INHERITANCE IN THE FEMALE LINE OF SIZE OF LITTER IN POLAND CHINA SOWS.

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Among the many problems of heredity yet to be solved, one of the most important is the determination in numerical values of the amount of transmission of different characters, which actually occurs. Galton (1897) and Pearson (1900) have given us their determinations of the theoretical correlation between parents and offspring, and several investigators have made mathematical determinations of the exact amount of correlation of various characters occurring between parents and offspring to the second generation.

One of the recent problems of the Department of Agriculture has been the determination of the size of litter of Poland China and Duroc Jersey sows, these results being recorded in Circular No. 95, Bureau of Animal Industry, "The Fecundity of Poland China and Duroc Jersey Sows," by the senior author of this paper. The results of this work may be summarized briefly as follows: "An undoubted increase is evident and the conclusion is inevitable, that, contrary to popular opinion, the Poland China breed has increased in fertility during the past twenty years. . . . The increase shown . . . (is) .48 per litter" (*n.* litters 54,515). The average size of litter in Poland Chinas, as recorded in the "American Poland China Record" and the "Ohio Poland China Record" for the first five years examined (1882–6) is 7.04, and for the last five years (1898–1902) 7.52. The Duroc Jersey records were calculated from the "National Duroc Jersey Record" for the years 1888–1902 inclusive with an average size of litter for the years 1893–1902 of 9.26 (*n.* litters 21,652). These records show no measurable change in size of litter for the period covered.

With these data at hand, it seemed desirable to continue the work to determine how far this character, size of litter, is inherited. The determination of the inheritance of fertility, fecundity, or number

of offspring born at one time, is a most valuable point, both from the standpoint of practical breeding and from that of theoretical consideration. Up to the present time, statistics on the inheritance of number of offspring in mammals is represented only by the work of Pearson, Lee, and Bramley-Moore (1899),[1] on man and thoroughbred race horses. In this work, it was found that fertility (total number of offspring) is inherited. By limiting the duration of marriage to fifteen years or more, the correlation of fertility in man was found to be larger than when no such limitation was made, a result which is in itself obvious. In the work on thoroughbred race horses the same method was employed making limitations according to number of coverings. In the work reported in this paper the total number of offspring born at one time is the only problem considered, and the length of the breeding period of parents does not effect the results except in the way shown, that the correlation decreases with the age of the sow.

In a recent paper by Castle and others (1906), this problem is taken up in *Drosophila ampelophila,* Löw. The results of this work show that there is "an unmistakable tendency for the larger parental brood to produce larger filial broods, but *not so much larger* as the difference in the parental brood would lead us to expect."

The method of work for the original problem is described by Rommel (1906) as follows:

"The Poland China records generally publish the registration of hogs according to the following plan or modifications of it:

MAGNET'S MODEL 2D, 135786.

Farrowed March 28, 1902. Litter, 7; raised—boars, 0; sows, 4.

Black with white points.

Bred and owned by W. C. Williams and Gardner, Bryant, Jay County, Ind.

Sire: Tecumseh Magnet, 46925; he by Nelson's Magnet, 35535, and out of Miss Rosa, 75542.

Dam: Gardner's Model, 122578, by Invincible Chief, 43377, etc.

"This is the registration of a sow on page 282 of volume 26 of the 'Ohio Poland China Record.'

"For each hog registered a card (size about 2 by 4⅞ inches) was written according to the following plan:

Name and number of dam.

[1] Mathematical Contributions, etc., VI, "Genetic (Reproductive) Selection: Inheritance of Fertility in Man, and of Fecundity in Thoroughbred Race Horses." *Phil. Trans.*, A, CXCII, 257–330.

Date progeny was farrowed. Number of pigs in litter; boars raised, sows raised; total raised.

Volume and page reference.

"The above litter would therefore appear on its card as follows:

Gardner's Model, 122578.			
March 28, 1902.	7—0—4.	4.	
			26/282

. . . . . .

"After all the cards for a volume were written, two clerks compared them with the originals and corrected errors in copying, one reading the original records while the other corrected the copies. After all the cards for a breed were written and verified they were sorted according to years; next the cards for each year were sorted according to size of litter farrowed; next the cards for each size of littler were arranged numerically according to the numbers of dams and duplicates thrown out, and finally the cards were counted and averages calculated. Cards were counted at least twice by different persons, and the calculations were made twice by different persons. In writing the cards for the 'American Poland China Record' from 1898 to 1902 the page reference was not included, which we now know was a mistake, as it is almost impossible to find a litter record without a page reference. The cards for the 'American Poland China Record' were arranged alphabetically at first, and it was necessary to rearrange them numerically, which eliminated a large number of duplicates."

. . . . . .

"The reader will recognize the fact that the probability of error in this work is large. Breeders are not always careful in reporting the number of pigs farrowed, often relying on the memory. In spite of the painstaking care of secretaries, errors in copying and typographical errors are sure to occur, and in our own work errors in copying, indexing, and counting were probable, although the cards were handled many times. At the same time, although the probability of error is large, the probability of these errors affecting the final results is very small on account of the large numbers used. A mistake of one hundred litters for one of the later years of the 'American Poland China Record' would affect the average for that year slightly, but would have no serious effect on the five-year average. The writer believes that the factor of error in these calculations has been reduced below the point of practical importance."

The litters for 1902 of the "American Poland China Record" were chosen for this additional work on inheritance. In addition to the information as described above, the mother of the dam was looked up and the size of litter in which she was far-

rowed was recorded. The date of farrowing of the dam was also recorded so that a card similar to the one illustrated above for the "American Poland China Record" for 1902 would now read:

U. S. Bell, 195,564.		
May, 1, 1902.	7—3—3.	6.
7.		'01.

The cards were then arranged according to the age of the mother at the time the dam named on the card was farrowed. This division is necessarily rough, but the cards were arranged according to the year of the birth of the dam, 1901, 1902, etc. Naturally the sows placed in any one year are not all exactly of the same age, but this rough segregation is enough to eliminate the factor of age as far as is practical and necessary in this work.

The method for calculating the correlation between mother and daughter is given by Davenport (1904), "Statistical Methods," pp. 44–47, using the modification adopted by Yule (1897), which is expressed in the formula

Coefficient of correlation

$$(r) = \frac{\Sigma f x' x''}{n} - v_1' v_1'' \frac{1}{\sigma' \sigma''}$$

in which x' and x'' are the deviations from an assumed integral mean of the subject and relative classes respectively, f is the frequency of the several combinations, n, total number of individuals, v_1' and v_1'', the differences between assumed and real means of the subject and relative classes, and σ' and σ'', the standard deviations of the subject and relative classes respectively. The standard deviation is obtained from the formula

$$\sigma = \sqrt{\frac{\Sigma(x^2 f)}{n}}$$

and is also equal to $\sqrt{v_2 - v_1}$. For a further discussion of these

terms and the method used in the determination, the reader is referred to the above-mentioned book by Dr. Davenport.

For the general reader, who may not be familiar with the approved methods of such work, it may be stated that the standard deviation (σ) is a relative measure, expressed in terms of the mean, of the concentration about the mean or average, and therefore is an excellent measure of the amount of variation. If the standard deviation (σ) is divided by the average (A), the result is the coefficient of variation (C) which expresses in percents the amount of variation of any group of individuals for the character under consideration. A large coefficient of variation indicates therefore that the individuals are not closely grouped about the average in the character measured, and consequently that the character is highly variable one and vice versa. The use of an assumed integral mean and then the correction of that mean by the subtraction of the product of the two differences between the assumed and real means ($-v'v''$ in formula) is merely for the sake of avoiding long fractions and has no effect on the general result. The formula

$$r = \frac{\Sigma f x' x''}{n\sigma'\sigma''}$$

represents the true formula for calculating correlations, but by the use of the first formula given, we get an identical result with very much less labor. In this formula, of course, x' and x'' are the deviations from the true mean of the subject and relative classes respectively.

The probable error (E) describes the probable limits above and below the calculated value within which the true value lies,—the absolute value being capable of determination only by an examination of an infinite number of cases. Thus $r = .0601 \pm .0086$ indicates that the coefficient of correlation probably lies between .0687 and .0515. The probable error for r is found from the formula

$$Er = \frac{0.6745\ (1 - r^2)}{\sqrt{n}}$$

for σ from the formula

$$E\sigma = 0.6745 \frac{\sigma}{\sqrt{2n}}$$

and for

$$A \text{ is } 0.6745 \frac{\sigma}{\sqrt{n}}$$

TABLE I.—Correlation of Size of Litters of Yearling Sows to Size of Litters in which Dams were Farrowed.—"American Poland China Record."—Litters of 1902.

Size of Litters in which Dams were Farrowed.	Size of Litters of Yearling Sows.																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1																		0
2				2	2	1	1			1								7
3		4	2	1	2	3	4	2	2	1								21
4			3	5	22	20	10	4	6									70
5		1	4	15	26	28	24	15	5	6	1							125
6		1	3	21	34	65	81	43	18	7	2							275
7	1	4	4	27	47	89	89	62	31	12	2							368
8	1	1	10	31	65	67	81	61	34	12	3	1	1					368
9		1	5	21	53	76	87	67	35	14	10	1	1					371
10	1	1	4	14	16	38	48	36	23	6	6							193
11		2	2	8	20	21	22	22	13	7	4							121
12		1	1	4	7	15	12	8	4	1	2	1						56
13			3	2	4	6	1	5		1			1					23
14					1	2	3	2	1	1								10
15										1								1
16																		0
17				1														1
	3	16	41	152	299	431	463	327	172	70	30	3	3	0	0	0	0	2010

TABLE II.—Correlation of Size of Litters of Two-Year-Old Sows to Size of Litters in which Dams were Farrowed. "American Poland China Record."—Litters of 1902.

Size of Litters in which Dams were Farrowed.	Size of Litters of Two-Year-Old Sows.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1							1	2		1						0
2				1			2	4	6	2			1			5
3				2	4	2	2	4	6	2			1			23
4			3	4	3	10	14	10	12	2	3	1	1	1		64
5			3	6	10	33	34	36	27	6	6	2			1	164
6	1	2	7	15	26	52	70	68	36	27	8	4	1			317
7		2	5	10	25	71	86	84	59	32	12	2	2	1		391
8		7	4	15	36	55	95	78	64	32	11	6	4	1		408
9	1	2	2	8	20	36	61	65	70	33	20	4	1	1		324
10			1	5	14	30	33	45	23	14	15	6	1			187
11		2	1	2	7	4	21	21	15	13	7	2			1	96
12			2	1	4	10	9	9	2	4	3	1				45
13					1	3	2	3	4	1	1					15
14							3	1	1	1	1		1			8
15																0
	2	15	28	69	150	306	431	426	319	168	87	28	12	4	2	2047

TABLE III.—Correlation of Size of Litters of Three-Year-Old Sows to Size of Litters in which Dams were Farrowed. "American Poland China Record."—Litters of 1902.

Size of Litters of Three-Year-Old Sows.

Size of Litters in which Dams were Farrowed.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1																		0
2						1	1	1	1									4
3		1		1	2	1	2	4	5			1					1	18
4		1			2	3	6	9	7	6	2		1					37
5		1	1	5	11	17	15	22	16	4	3	3	1					99
6	1	1	3	5	14	27	37	29	35	14	12	3						181
7	1		2	9	19	25	50	48	31	34	12	4	2					237
8	1		5	3	13	31	40	47	35	22	18	2	3		1	1		222
9				3	8	17	33	30	31	24	8	2	3	2				161
10	1		3		6	11	16	25	24	17	4		1	1	1			110
11				4	5	5	14	13	12	6	4	3	1					67
12			1			2	3	1	2	4	5							18
13						1												1
14									1									1
15																		0
16								1										1
17																		0
	4	4	15	30	80	141	217	230	200	131	68	18	12	3	2	1	1	1157

TABLE IV.—Correlation of Size of Litters of Four-Year-Old Sows to Size of Litters in which Dams were Farrowed. "American Poland China Record."—Litters of 1902.

Size of Litters of Four-Year-Old Sows.

Size of Litters in which Dams were Farrowed.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1								1				1				2
2									1	1						2
3			1		1		1	2	1	3						9
4				1		2	5	5	4	3	2	2				24
5				2	3	5	6	11	8	7	2			1		45
6				2	6	7	13	18	8	17	3	2	1	1		78
7		1		2	6	13	22	24	32	16	4	2		1		123
8			1	3	5	10	15	23	26	24	6	6	1	1	1	122
9		1	1	3	8	9	18	18	15	20	10	1	2	3		109
10				1	4	5	5	10	8	11	3			1		48
11				2	2	5	1	5	6	1	5	2	1			30
12					1	2		1	2	3	1					10
13						1	1									2
14						1				1						2
15																0
	0	2	3	16	36	60	87	118	111	107	36	16	5	8	1	606

TABLE V.—Correlation of Size of Litters of Five-Year-Old Sows to Size of Litters in which Dams were Farrowed. "American Poland China Record."—Litters of 1902.

Size of Litters in which Dams were Farrowed.	Size of Litters of Five-Year-Old Sows.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1																0
2												1				1
3					1			1	2							4
4						2	1	2	3	2					1	11
5					1	3	3	6	6	4	2	2				27
6		1	1	1	4	8	4	10	6	8	7	1	1	2		54
7				1	1	8	12	10	13	11	6	1	3			66
8				2	3	3	11	14	10	4	3	3				53
9		2		2	4	3	8	11	12	6	4	2				54
10				1		4	3	5	4	3	3	2	1	1		27
11						1	3	2	2	4	1					13
12							1	2	1				1			5
13					1		1	1	1	1	2		1			8
14							1		1							2
15																0
	0	3	1	7	15	32	48	64	61	43	28	12	7	3	1	325

TABLE VI.—Correlation of Size of Litters of Sows One to Five Years Old to Size of Litters in which Dams were Farrowed. "American Poland China Record."—Litters of 1902.

Size of Litters in which Dams were Farrowed.	Size of Litters of Sows One to Five Years Old.																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1								1				1						2
2				3	2	2	3	3	2	3		1						19
3		5	3	4	10	6	9	13	16	6		1	1				1	75
4		1	6	10	27	37	36	30	32	13	7	3	2	1	1			206
5		2	8	28	51	86	82	90	62	27	14	7	1	1	1			460
6	2	5	14	44	84	159	205	168	103	73	32	10	3	3				905
7	2	7	11	49	98	206	259	228	166	105	36	9	7	2				1185
8	2	8	20	54	122	166	242	223	169	94	41	18	9	2	2	1		1173
9	1	6	8	37	93	141	207	191	163	97	52	10	7	6				1019
10	2	1	8	21	40	88	105	121	82	51	31	8	3	3	1			565
11		4	3	16	34	36	61	63	48	31	21	7	2		1			327
12		1	4	5	12	29	25	21	11	12	11	2	1					134
13			3	2	6	11	5	9	5	3	3		2					49
14					1	3	7	3	4	3	1		1					23
15										1								1
16								1										1
17				1														1
	9	40	88	274	580	970	1246	1165	863	519	249	77	39	18	6	1	1	6145

The calculation of the correlation between sizes of litters in two consecutive generations in the female line gives the following results:

TABLE VII.—Correlation in Size of Litter of Poland China Sows between Mother and Daughter.—"American Poland China Record."

Age of Daughters.	Number of Cases.	A. M.	A. D.	σ M.	σ D.	r.	Er.
1 year.	2010	7.908	6.6451	2.0764	1.7582	.1088	.0149
2 years.	2047	7.6927	7.5598	1.9818	1.9415	.0885	.0148
3 years.	1157	7.5809	7.8799	1.9615	2.0693	.0883	.0197
4 years.	606	7.6304	8.2821	1.9856	2.0661	.0379	.0274
5 years.	325	7.6738	8.4031	2.1001	2.1571	.0032	.0375
1–5 years.	6145	7.7349	7.4391	2.0202	2.0312	.0601	.0086

Conclusions.

From the first work in statistics of fecundity of sows (Rommel, 1906), it is evident that in Poland China hogs there has been an increase of .48 in the size of litter in the twenty years between 1882 and 1902. This result may be attributed to one of two factors. It is either the result of selection (probably more or less accidental) of sows (and boars) from large litters and a consequent inherited tendency toward the production of larger litters, or a gradual improvement in the environmental conditions, bringing about the same result by external factors. From the first work it is impossible to do more than theorize as to the true cause, the theories being based, of course, on a knowledge of the usages of breeders.

The tabulation of the sizes of litters from mothers and daughters and the determination of the coefficient of correlation (r) shows that there is an actual correlation between the size of litters of two successive generations, and we are consequently justified in concluding that size of litter is a character transmitted from mother to daughter. The coefficient of correlation for the five years is small (.06), but it is appreciable and consequently it would appear proved that, by judicious selection for breeding purposes of sows from large litters, the average for the breed may be increased. This, combined with the fact that the average has actually been increased, gives us evidence that may be considered very strong.

Unfortunately the cards used in this work for litters for 1902 of the "American Poland China Record" were not written to include the sire, and we are consequently unable at present to determine from these data the influence of the boar on the size of litter of a sow of his offspring. This work is being continued, however, and these additional data are being recorded.

The decrease from .1088 to practically zero (.0032) from the first to the fifth year does not necessarily mean that the inheritance of fecundity is lost as a sow grows older, but probably indicates that inheritance from the first dam gradually plays relatively less and less of a part in the determination. So many other factors, body strength, maturity, and functional habit, can influence this, that the inherited tendency seems to lose its influence. The average for five years (.06) is, however, large enough to be of value to the breeder, and with the large numbers here used (6145) the probable error is small (.0086), and our results more nearly a true statement of the conditions of inheritance.

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